Advanced Lightweight Metal Matrix Composites Segmented Optic Manufacture

NASA Contract NNX 10CP73P

Small
Business
Innovation
Research

Welded AlBeMet Mirrors

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North Chelmsford, MA

INNOVATION

Large metal mirrors can be made by welding smaller pieces together. Currently beryllium mirrors are limited to1.2m diameter. AlBeMet welds are extremely fine grained and can be diamond point turned and polished.

TRL Assessment:: 3 at Start to 6 at End of Project

TECHNICAL ACCOMPLISHMENTS

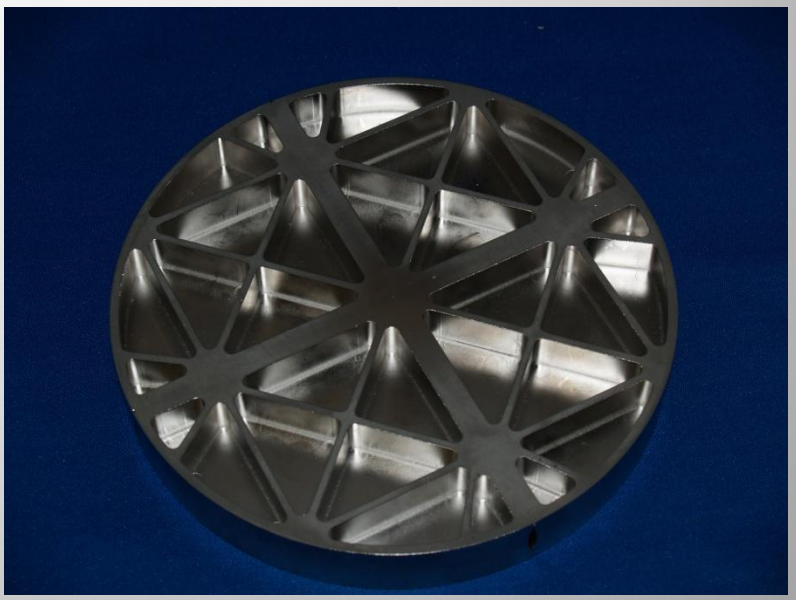
- Development stage: a prototype six-inch diameter flat AlBeMet mirror was polished
- The mirror was then cut into 4 pieces and welded back together
- The mirror was then optically polished again
- The same optical figure was achieved after welding

FUTURE PLANS

- Develop a larger mirror design based on existing lidar receiver telescopes

GOVERNMENT/SCIENCE APPLICATIONS

- NASA has a number of space lidar applications in the works
- A phase 2 SBIR is planned to demonstrate the ability to manufacture a 2m class mirror using the welding technology
- NASA missions include ICESat-2 (ATLAS) and DESDynI
- Demonstrated NASA/USG customer interest to date.
- Estimated NASA mission/project cost savings due to SBIR innovation/product: $5M



Six-inch diameter welded AlBeMet mirror

COMMERCIALIZATION

- AlBeMet Welded mirrors
- No patents yet
- Primary target market sectors: potential for DoD and commercial applications
- Application of EB Welding Technology is available for sale

Goddard Space Flight Center
Subtopic Name: Optics Manufacturing,
Number: S2.05
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Phase 1 Objective

- Develop a manufacturing process capable of producing optics up to 2 meters through the design and testing of a lightweight metal matrix composite segmented optic
- Segments of AlBeMet® 162H were Fusion Bonded (E-beam welded)
- Goal is to demonstrate near monolithic material properties from segmented optic and perform as if it were a monolithic optic

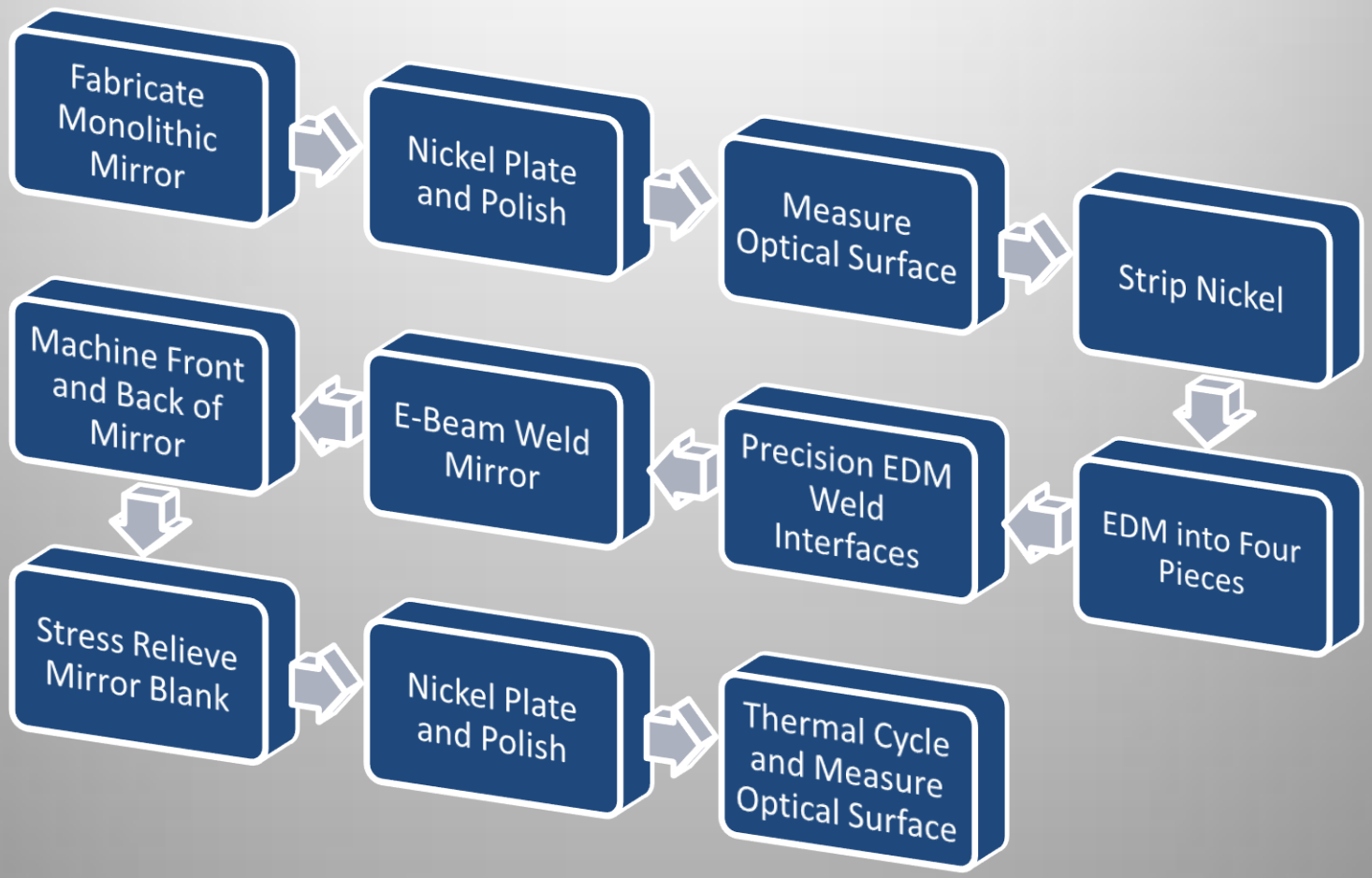
Benefits

- A welded segmented mirror may offer:
  - Ability to make large mirrors
  - More design options for engineering
  - Lower cost and better lead time
  - Lower mission risk
    - Mirror can be repaired

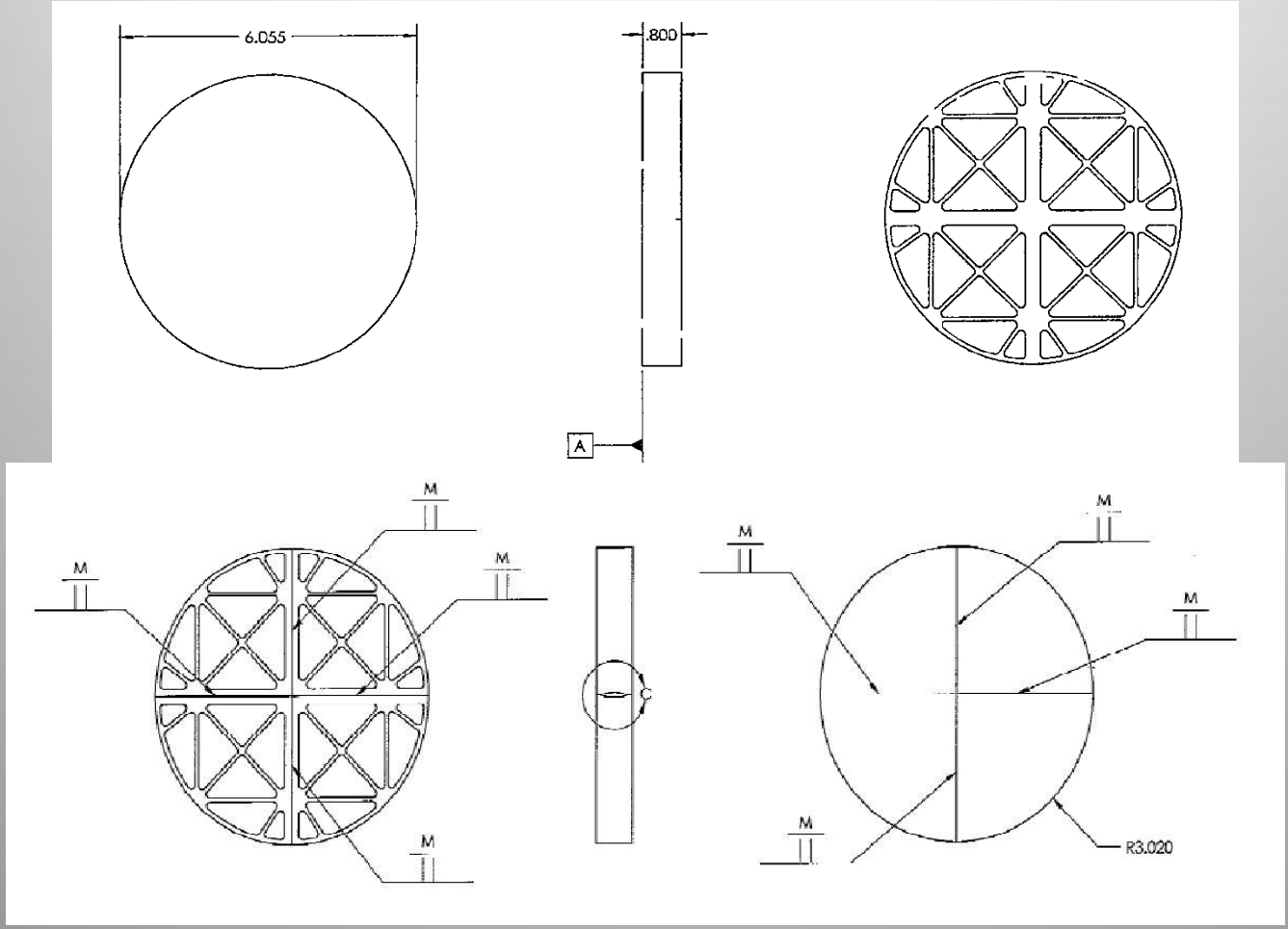
Mirror Design and Development

- 6” diameter flat mirror design was chosen
  - Minimizes the effect of extraneous factors on the performance of the final mirror
    - Easier to polish and measure results
    - Designed to validate the same prescription when segmented and then reassembled
    - Any material lost due to segmenting the optic would not change the prescription

Mirror Fabrication Process



Mirror Design



Mirror Design

Mirror Design and Development

- Incorporated light-weighting cavities and stiffening ribs
  - Thicker ribs were required along the proposed cutting/welding lines to facilitate the machining of those surfaces when the mirror was segmented
    - While the total thickness is wider, the cavity in the middle is hollow offsetting the mass of the thicker rib
  - The mirror was designed to be cut into four (4) equal segments

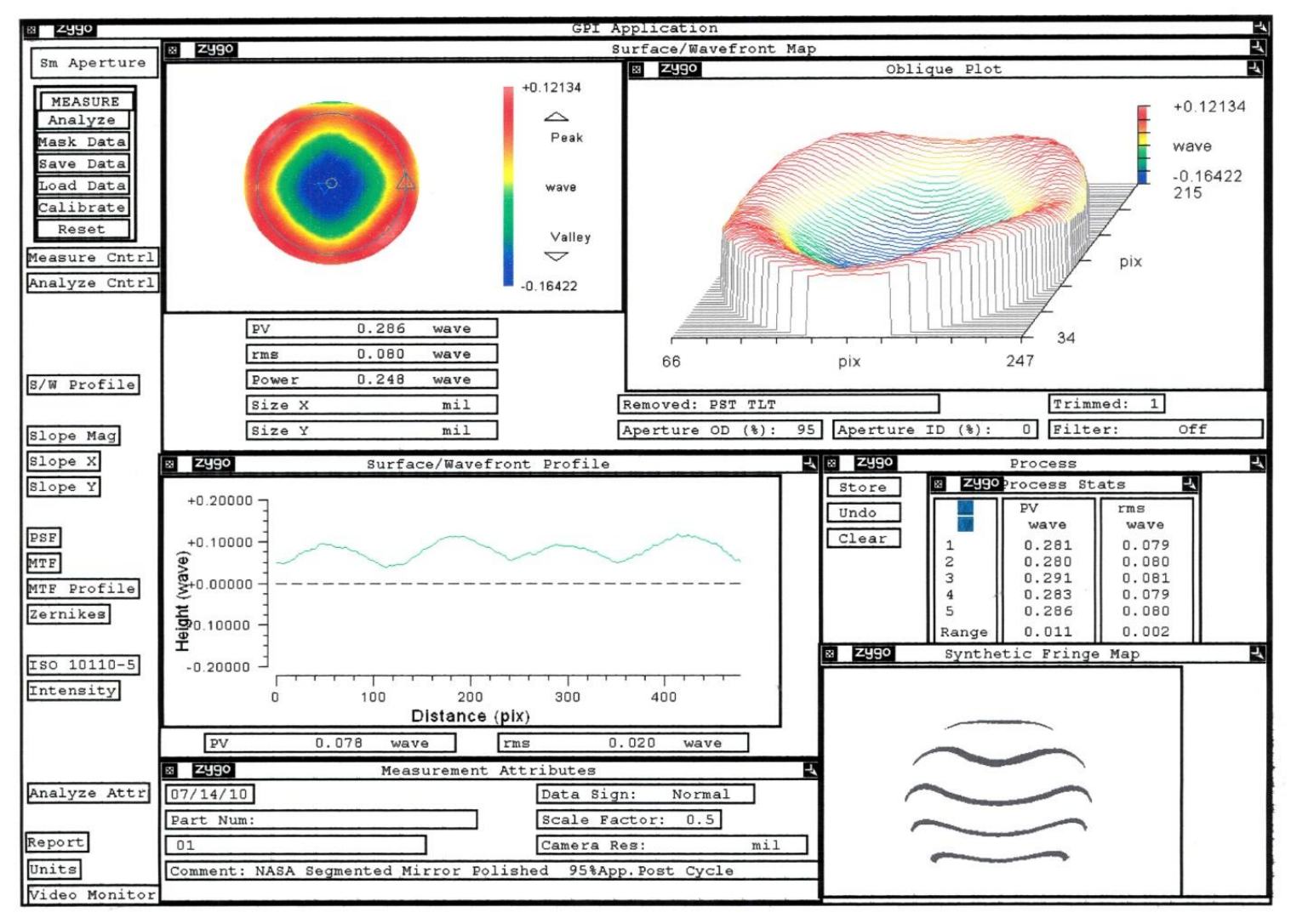
Monolithic Mirror Fabrication

- Machining work was performed using Hardric's Kiwa KH-45 4-axis horizontal machining center
- Hardric closely followed Materion's suggested fabrication process for AlBeMet® optics including
  - Stabilization
  - Temperature cycling
  - In-process inspection checks
- Mirror was ground in preparation of Ni plating to a flatness of 0.0001"

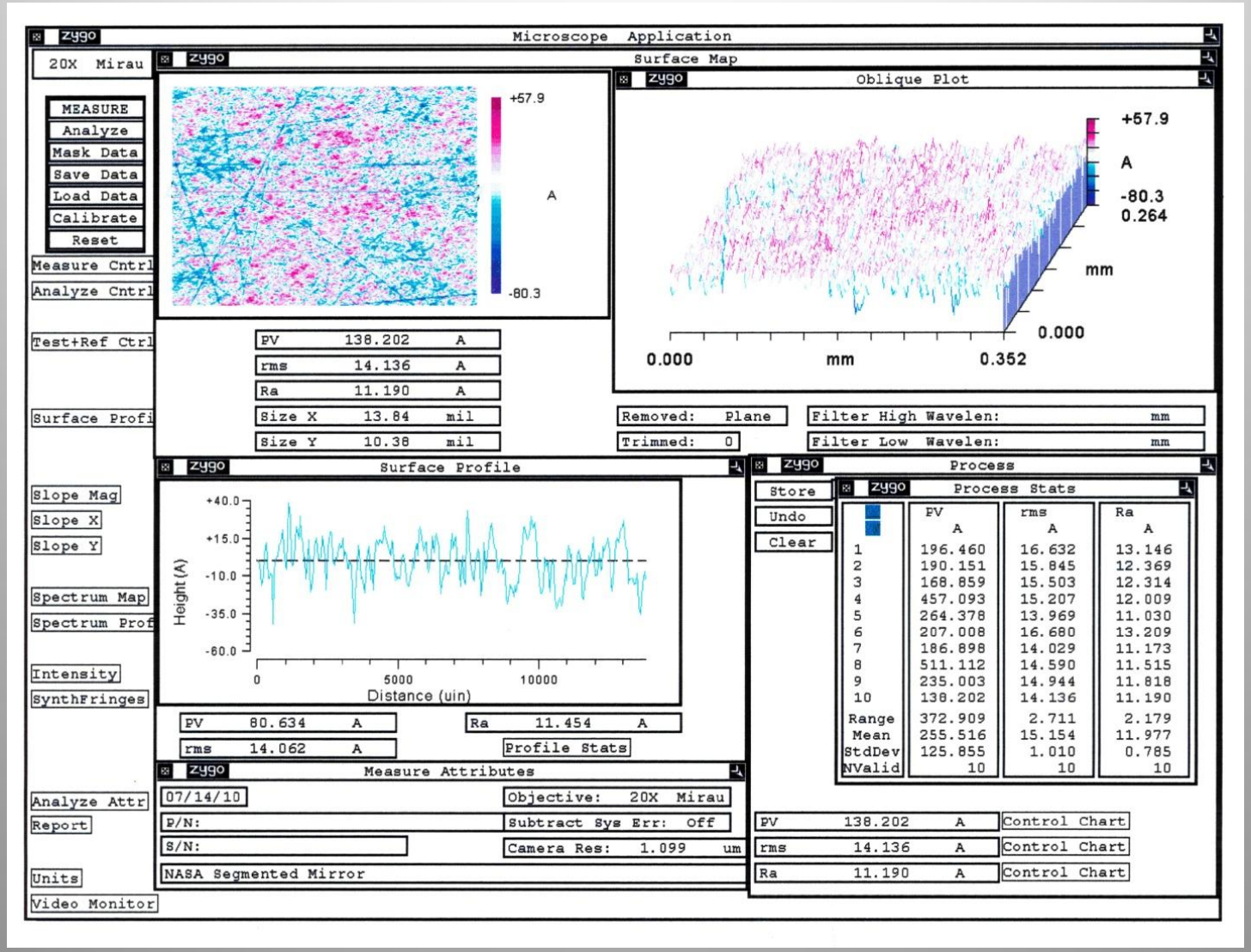
Monolithic Mirror Fabrication

- Mirror was plated with high-phosphorous nickel to a thickness between 0.003” – 0.004” in accordance with specification AMS 2404, class I
- After nickel plating, the mirror was stabilized, polished to obtain a finished optic
  - Stabilized mirror achieved a surface figure within ¼ λ (0.286λ) at 633nm with a surface roughness of 15Å rms

Interferogram of Monolithic Mirror

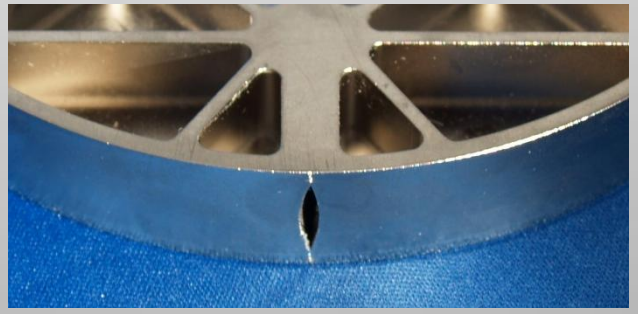


Profilometer scan of Monolithic Mirror



Segmented Mirror Fabrication

- Chemically stripped the nickel plating
- Mirror segmented using EDM into four quarter sections
- EDM'd ellipse in the center of each rib to aid in E-Beam Welding

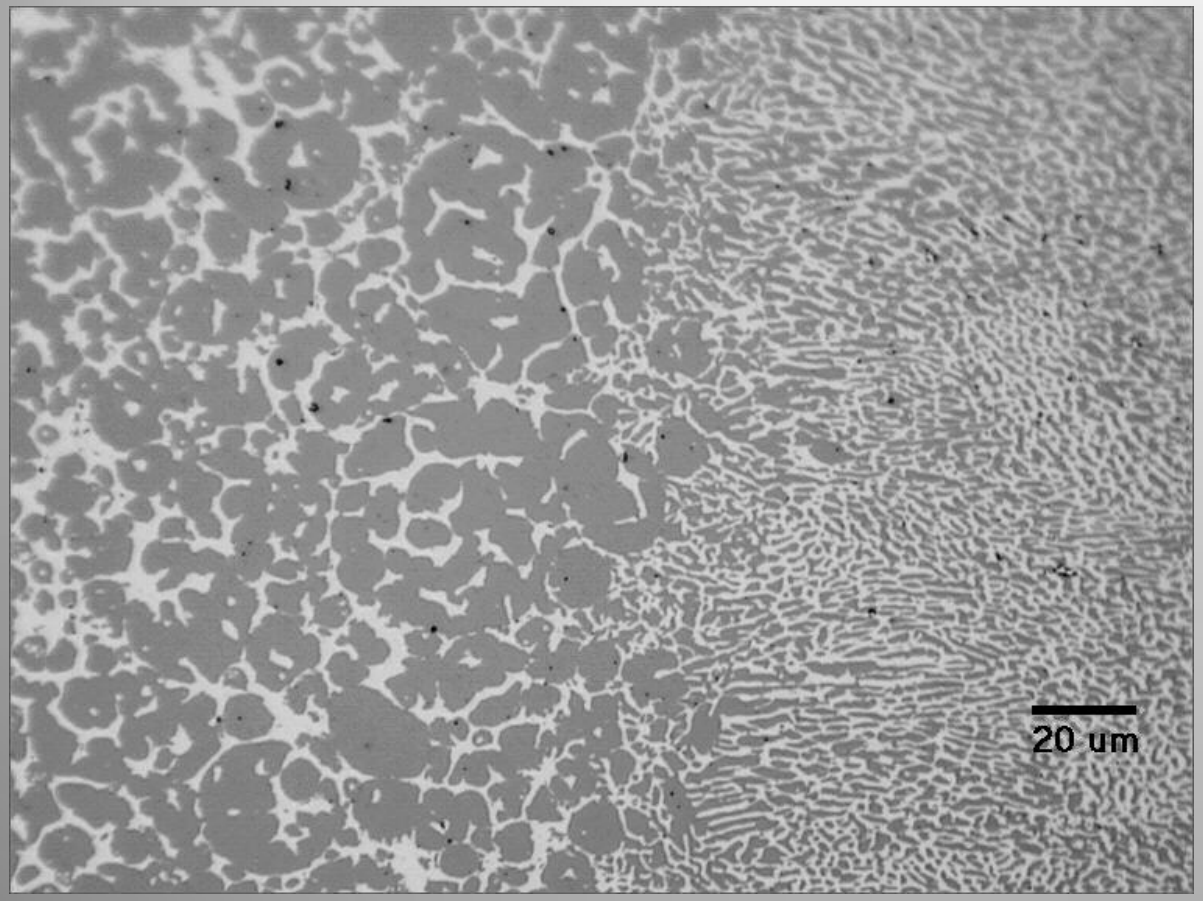


- The segments were stabilized and cleaned before being delivered to Acceleron for the welding process

AlBeWeld® Information

- **Electron Beam Welding is a welding process that:**
  - Utilizes a precise finely focused stream of electrons as the energy source for melting
  - Process is done in a vacuum chamber
  - Generates ultra-fine grain structure
  - Requires no filler alloy
  - Results in minimal distortion

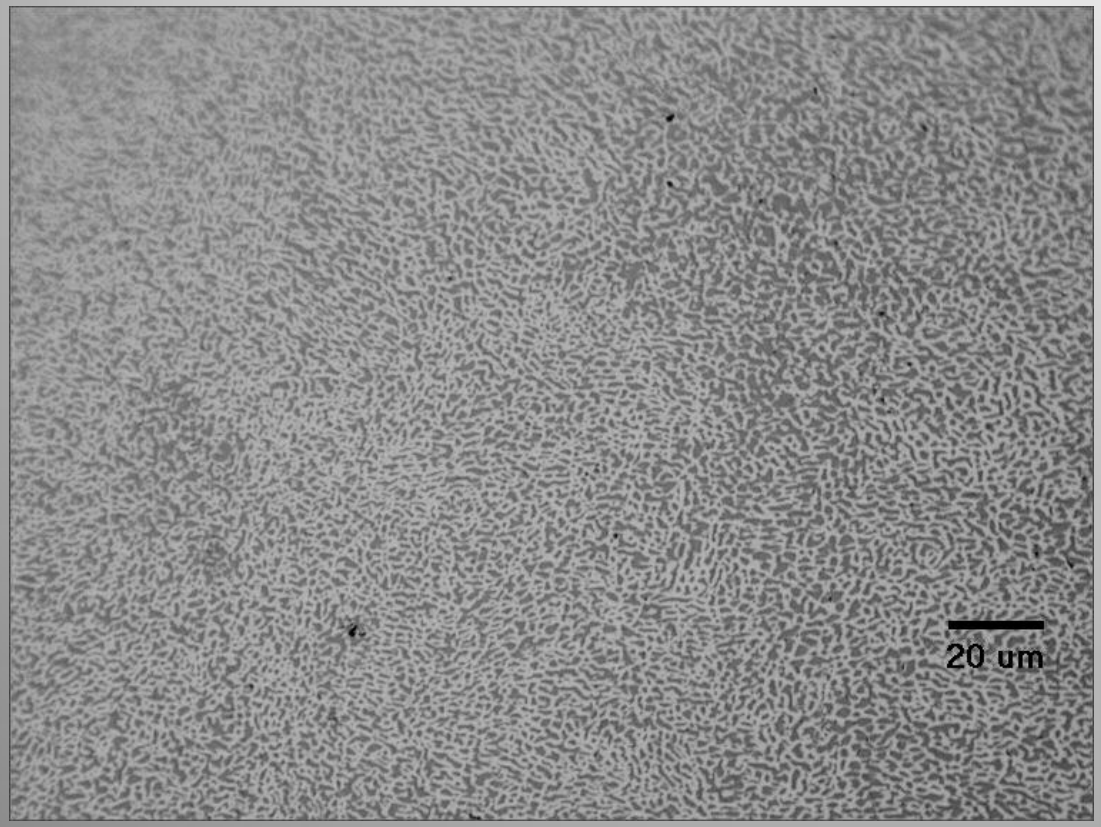
AlBeWeld® Base Metal/Weld Zone Interface



Weld Zone Microstructure

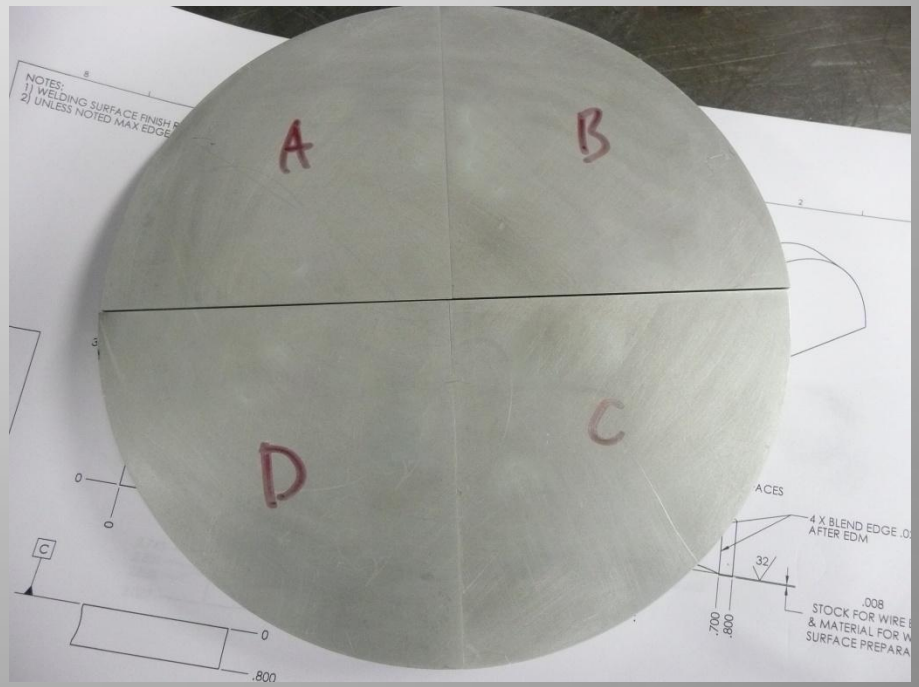
AlBeWeld® Microstructure

Weld Zone- Center



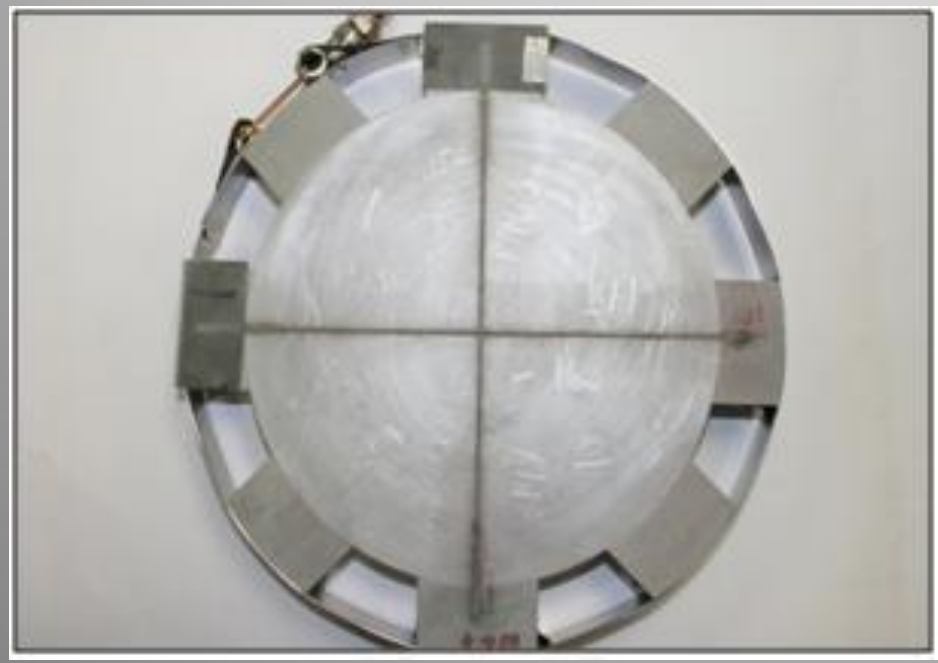
Segmented Mirror Fabrication

- Segment Mirror sections

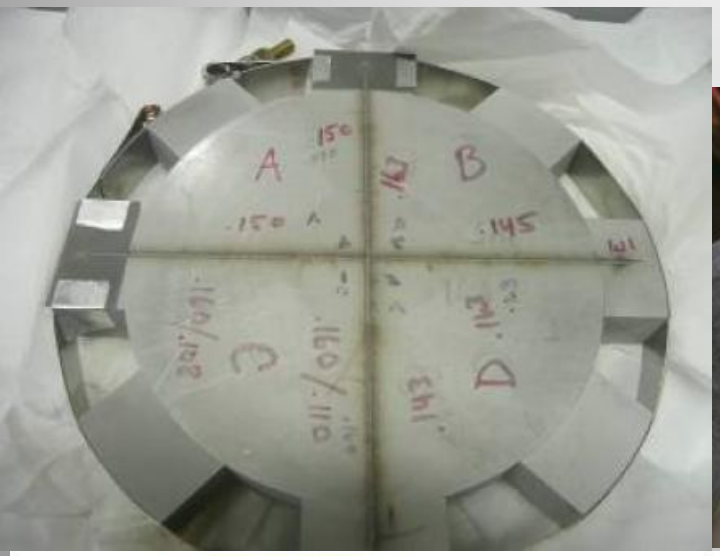


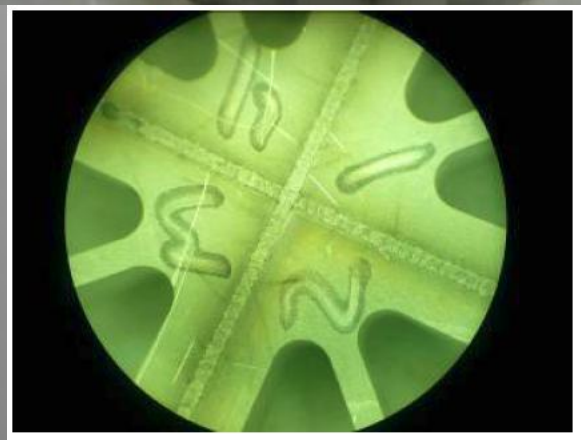
Segmented Mirror Fabrication

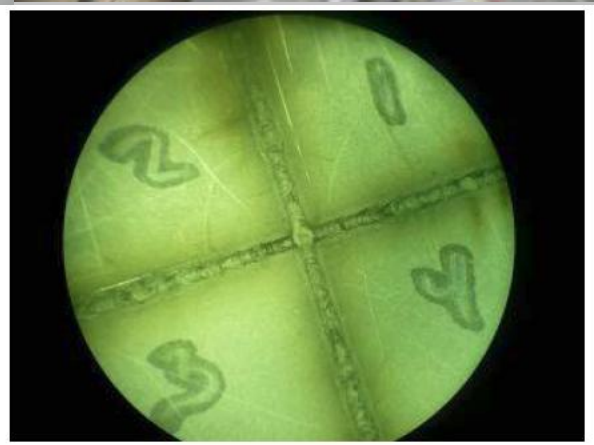
- Welds along the mirror surface were done first
- Mirror was flipped and the back side was welded



Segmented Mirror E Beam Welding





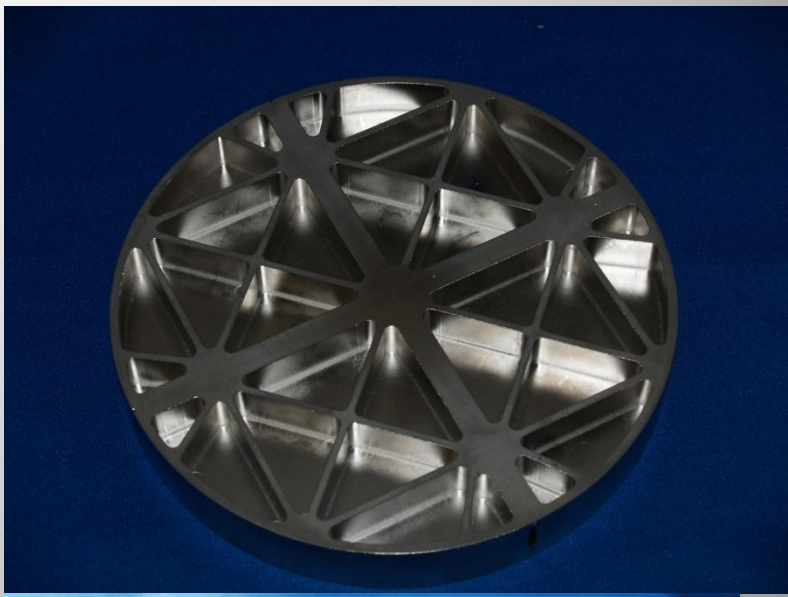


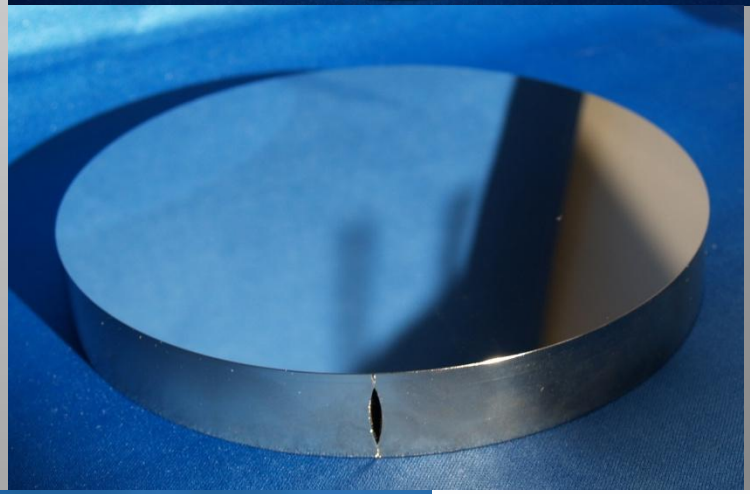
Segmented Mirror Fabrication

- Approximately 0.040” of material was removed from the mirror face and the weld seams appeared very clean
- A small amount of material was also removed from the back side of the mirror to clean up the appearance of that weld
- The mirror was stress relieved before being ground to 0.0001” flatness and nickel plated

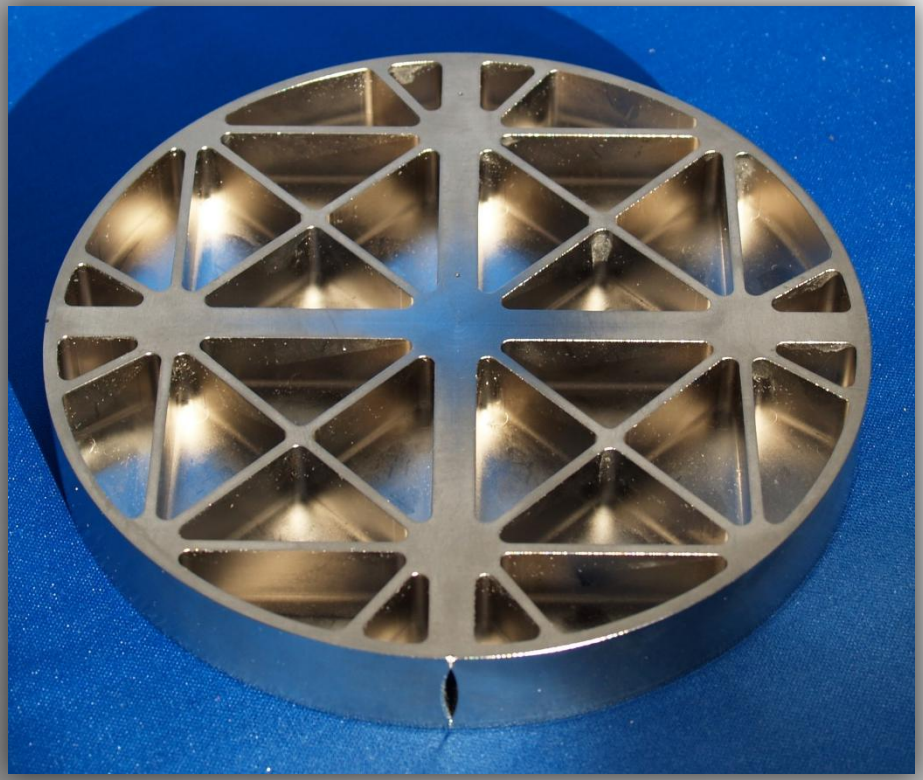
Segmented Mirror Fabrication

- The E-Beam welded mirror was polished using same process as monolithic mirror
- Mirror achieved a surface figure of less than 0.7λ at 633nm. Surface roughness measured at 16.5Å
  - A better surface figure could have been achieved with additional time



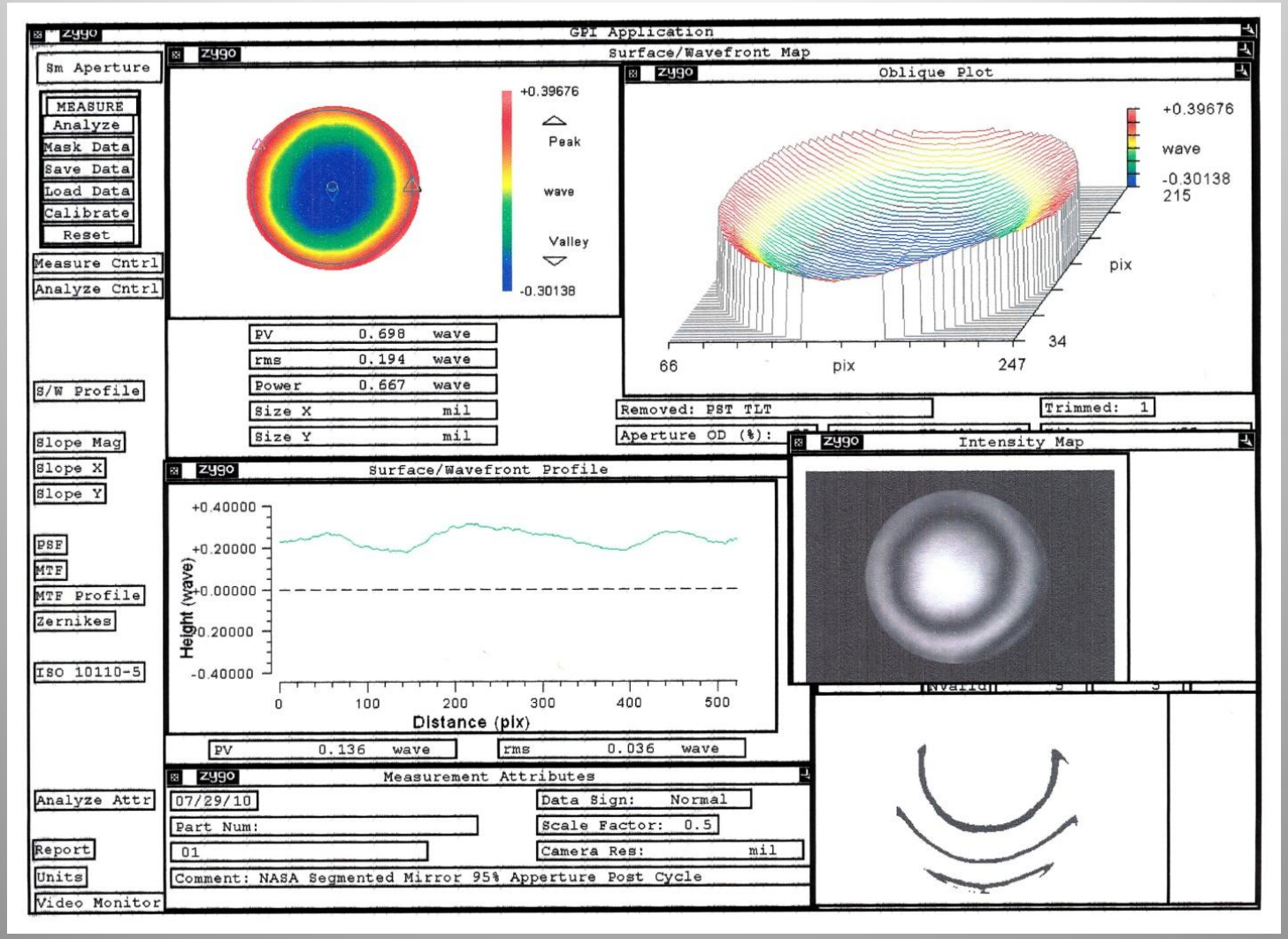


Segmented Mirror Fabrication



Finished Mirror

Interferogram of Segmented Mirror



Monolithic -vs- Segmented Mirror Characteristics

- Two characteristics were used in evaluating each of these mirrors
  - The surface figure measured in waves (λ) at 633nm
    - Goal of achieving less than 1λ
  - Surface roughness measured in angstroms (Å)
    - Surface roughness wasn't targeted as long as the surface figure was achieved

Monolithic -vs- Segmented Mirror Characteristics

	Monolithic Mirror	Segmented Mirror
Surface figure (λ at 633nm)	0.286	0.698
Surface roughness (Å rms)	15.5	16.5

- Improved results could be obtained with further processing of the segmented mirror- **Ran out of time**

Segmented Mirror- Other Observations

- During final polishing of the segmented mirror, it was noticed that the weld lines appeared in interferograms taken after temperature cycling (stabilization)
  - Lines were not seen with the naked eye in visible light
  - Lines were examined further to try and determine their nature and their potential effect on the performance of the mirror

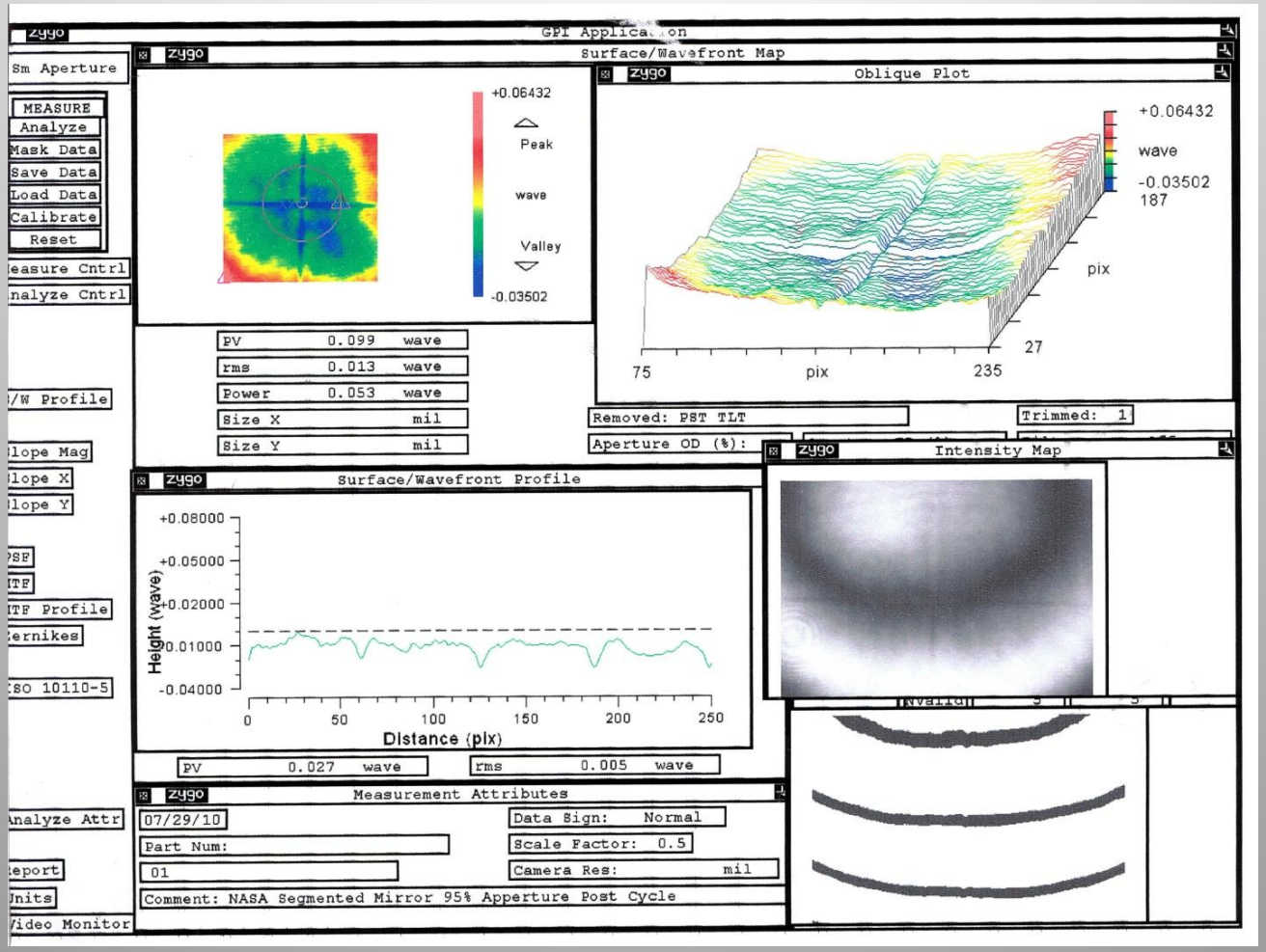
Segmented Mirror- Other Observations

- Analyzing the images taken with the Zygo non-contact profilometer the lines appear to be depressions in the surface

Segmented Mirror- Other Observations

- Lines did not seem to affect the overall surface figure
- To get a better idea of the size and nature of the lines, a smaller area of approximately 4.0 in^2 from the center of the mirror was scanned using the 6” Zygo Interferometer

Segmented Mirror- Other Observations



Interferogram of central 4 sq. in of segmented mirror

Segmented Mirror- Other Observations

- Examining the surface profile shows these depressions to be on the order of 1/50λ in depth (12 to 13 nanometers)
- The depressions do not appear to disrupt the surface figure from one segment to another, and the nickel plating remains adhered and undisturbed
- Due to time constraints, Hardric could only perform one round of polishing and stabilization on the mirror
  - **This anomaly should go away with additional polishing**

Segmented Mirror- Other Observations

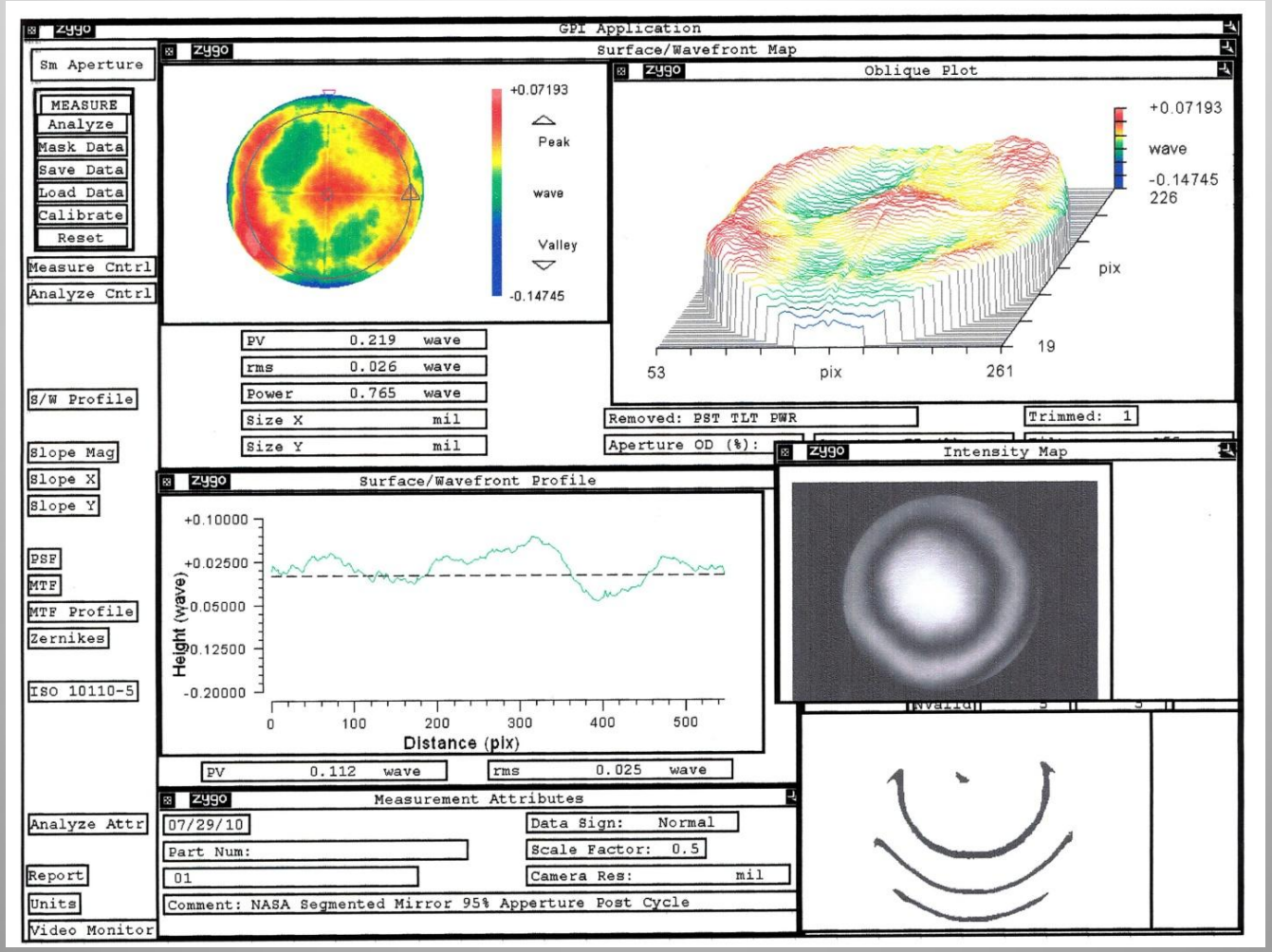
- We can take advantage of the weld lines to clearly define the individual segments of the mirror and examine how the segments interact with each other
- When looking at the surface figure with & without the power removed the surface figure flows smoothly from one segment to the next
  - Indicating that the segmented mirror responded to the polishing and stabilization process in the same manner as a monolithic mirror
- Segments did not move independently, even after temperature cycling

Segmented Mirror Conclusion

- Objective of this project was to determine the feasibility of being able to produce a mirror out of welded segments with comparable performance to a monolithic mirror
- Feasibility of creating a high-performance mirror out of welded segments of AlBeMet 162H has been proven
- Phase II / Future Work
  - Continue evaluation of 6” optic to stabilization cycle and understand weld zone anomalies
  - Increase the segments to a size and configuration that can be made into a .5 to 1 meter astronomical mirror

Questions?

Segmented Mirror- Other Observations



Interferogram of segmented mirror with power removed